Synopsis

Frequency response analysis (FRA) of transformers is universally accepted as a highly sensitive tool to detect deformations in its windings. This is evident from the fact that customized commercial equipment (popularly called FRA or SFRA instruments) are used and recently the IEEE has issued a draft trial-use guide. Nevertheless, use of FRA is still limited to only detection and there is little progress towards its use for localization of winding deformation. Toward this end, a possible approach would be to compare the healthy and deformed systems in a suitable domain, e.g., their respective models could be compared. In this context, the mutually-coupled ladder network is ideally suited because not only does it map the length of the winding to sections of the ladder network, but, also inherently captures all subtle intricacies of winding behaviour under lightning impulse excitations insofar as the terminal response, internal oscillations and voltage distributions are concerned. The task of constructing a ladder network from frequency response is not trivial, and so exploration of newer methods is imperative.

A system can comprehensively be characterized by its frequency response. With this as the starting point, many approaches exist to construct the corresponding rational function (in s-domain). But, the subsequent step of converting this rational function into a physically-realizable mutually-coupled ladder network has, as yet, remained elusive. A critical analysis of the circuit synthesis literature reveals that there exists no analytical procedure to achieve this task, a fact unequivocally stated by Guillemin in his seminal book "Synthesis of Passive Networks". In recent years, use of iterative methods to synthesize such ladder networks has also been attempted with some degree of success. However, there exists a lot of scope for improvement. Based on this summary, the objectives of this thesis are as follows-

- *Development of an analytical procedure, if possible, to synthesize a mutually-coupled ladder network starting from the s-domain representation of the frequency response*
- *Construction of a nearly-unique, mutually-coupled ladder network employing constrained optimization technique and using frequency response as input, with time-efficiency, physical realizability and repeatability as its features*

In Chapter 2, analytical solution is presented to convert a given driving-point impedance function (in s-domain) into a physically-realizable ladder network with inductive couplings (between any two sections) and losses considered. The number of sections in the ladder network can vary, but, its topology is assumed fixed. A study of the coefficients of the numerator and denominator polynomials of the driving-point impedance function of the ladder network, for increasing number of sections, led to the identification of certain coefficients, which exhibit very special properties. Generalized expressions for these specific coefficients have also been derived. Exploiting their properties, it is demonstrated that the synthesis method essentially turns out to be an exercise of solving a set of linear, simultaneous, algebraic equations, whose solution directly yields the ladder network elements. The proposed solution is novel, simple, and guarantees a unique network. Presently, the formulation can synthesize a unique ladder network up to 6-sections. Although it is an analytical solution, there are issues which prevent its implementation with actual FRA data.

Keeping the above aspect in mind, the second part of the thesis presents results of employing an artificial bee colony search algorithm for synthesizing a mutually-coupled lumped-parameter ladder network representation of a transformer winding, starting from its measured magnitude frequency response. The bee colony algorithm is modified by defining constraints and bounds to restrict the search-space and thus ensure synthesis of a nearly-unique ladder network, corresponding to each frequency response. Ensuring near-uniqueness while constructing the reference circuit (i.e., a uniform healthy winding) is the objective. The proposed method is easy to implement, time-efficient, ensures physical realizability and problem associated with supply of initial guess in existing methods is circumvented. Experiments were performed on two types of actual, single, isolated transformer windings (continuous-disc and interleaved-disc) and the results are encouraging.

Further details are presented in the thesis.